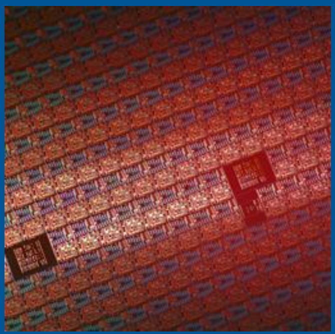
Accelerating the next technology revolution

Biased target deposition for EUV mask blanks



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Outline

- History of EUV deposition techniques
- Why IBD is used for mask deposition
- Shield defects may be liberated by inherent IBD overspray
- Biased Target Deposition (BTD) a potential solution.
- Proof of concept tests
- Future plans
- Summary

History of EUV deposition techniques

- E-beam with ion polishing-Early 1980s
  - Demonstrated useful reflectivity for astronomy and microscopy.
  - E Spiller
- Physical Vapor Deposition (PVD) –Late 1980s-present
  - Magnetron demonstrated >50% reflectivity for Mo/Si, people start thinking about lithography.
  - D Windt, S Vernon, D Stearns, A Hawryluk
  - Still dominant technology for optics coating.
- Ion beam -1995-present
  - Demonstrated low defect levels, majority of low defect work performed with IBD.
  - P Kearney

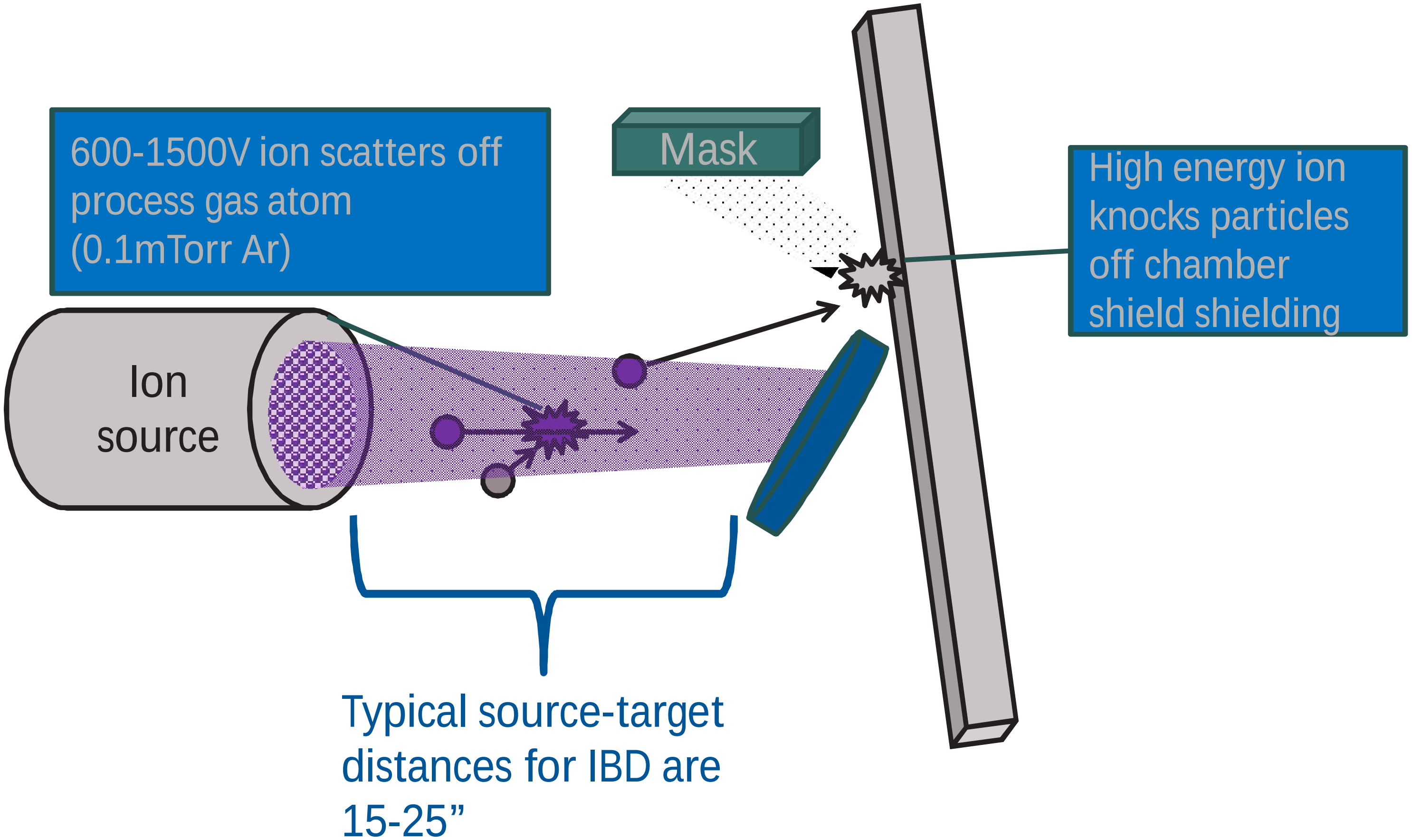
Why is IBD used for mask production

- In 1994 Intel gave the team at LLNL 1 year to produce EUV multilayers with <0.1 defect per cm^2.
  - Attempts to reduce defects in the existing magnetron tools bottomed out ~100x the goal.
    - Not too surprising since they were not designed for low defects.
    - Existing magnetron technology suffered from re-deposition and arcing targets which lead to high defect levels.
  - First IBD attempt achieved 10X the goal.
  - Team of industry particle experts from chipmakers and suppliers supported teaming with Veeco on IBD.
    - Experts felt that keeping the plasma away from the target and substrate would reduce defects.;
- Since then the industry has been evolving the basic Veeco IBD design to try and reduce defects.
  - Initial progress was good achieving the goal of 0.1 cm^2 within the year.

One factor that may limit IBD defect levels is ion beam overspray

- It is now well established that a small fraction of the ion beam misses the target due to scattering and other effects.
- The current Hypothesis is that these ions hit the shield and liberate particles
  - Current mask defects are dominated by shield material.
  - Ions hitting shield can release similar defects.
- Much effort has been expended reducing overspray missing the target, but some overspray is inherent to the IBD process.
- Work continues to reduce the scattering of ions onto the shields in IBD.
- IBD remains the process of record for masks.
- As a <u>risk reduction</u> strategy SEMATECH is investigating alternate mask deposition techniques.

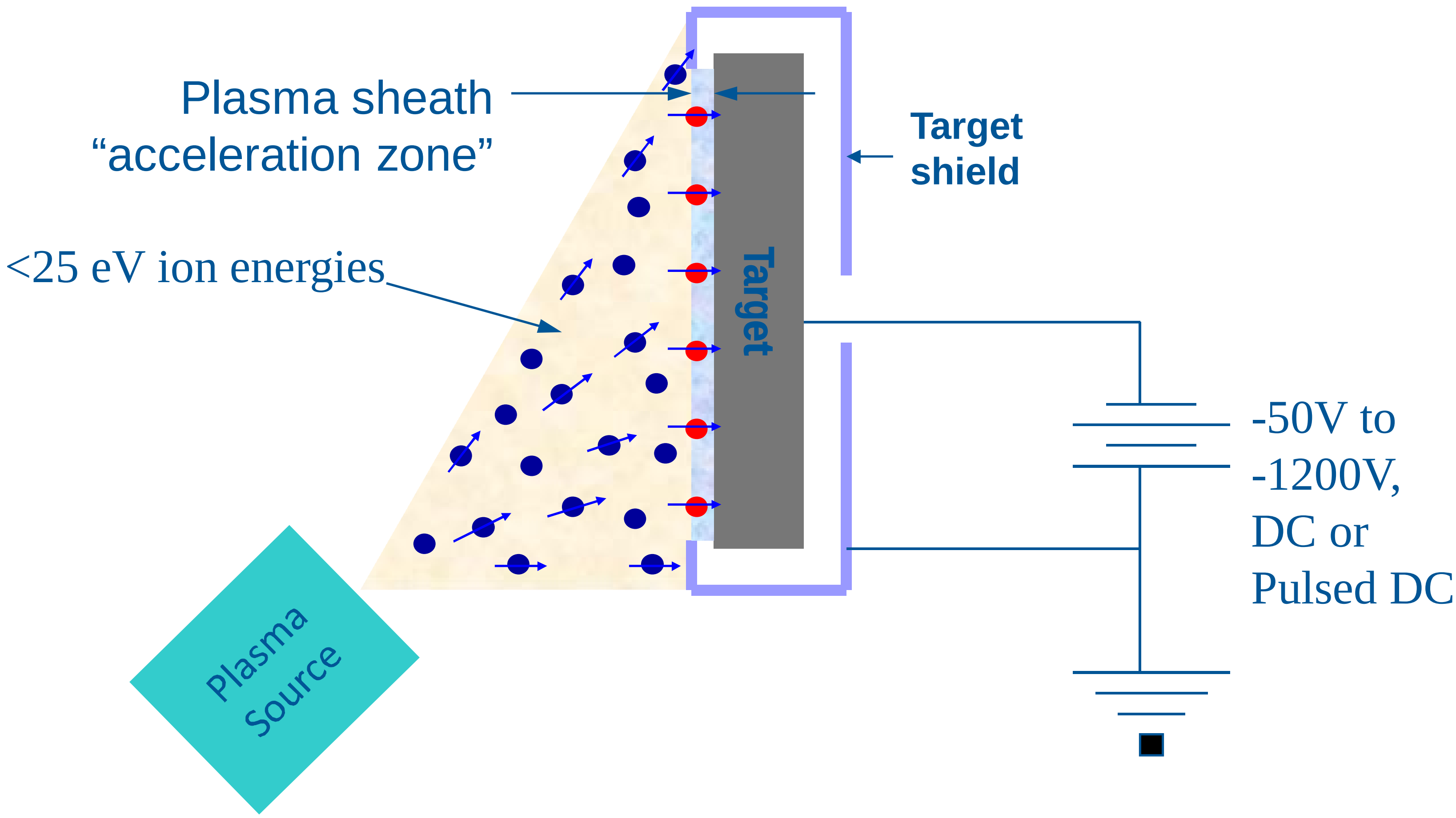
Long path of high energy ions leads to scatter and defects in IBD systems



Physical Vapor Deposition has come a long way since 1994!

- Many of these improvements reduce defects.
  - Moving magnet arrays reduce redeposition and defects.
  - Pulsed power reduces arcing and the resulting defects.
  - Magnetic field designs improve target utilization and redeposition.
- It is time to re-consider magnetron deposition for low defect mask blanks.
  - The flavor of magnetron deposition being investigated is Biased Target Deposition (BTD).
  - Collaborating with 4Wave to study the possibility of using BTD to support future EUV mask nodes.

BTD – High energy ions only exist near the target

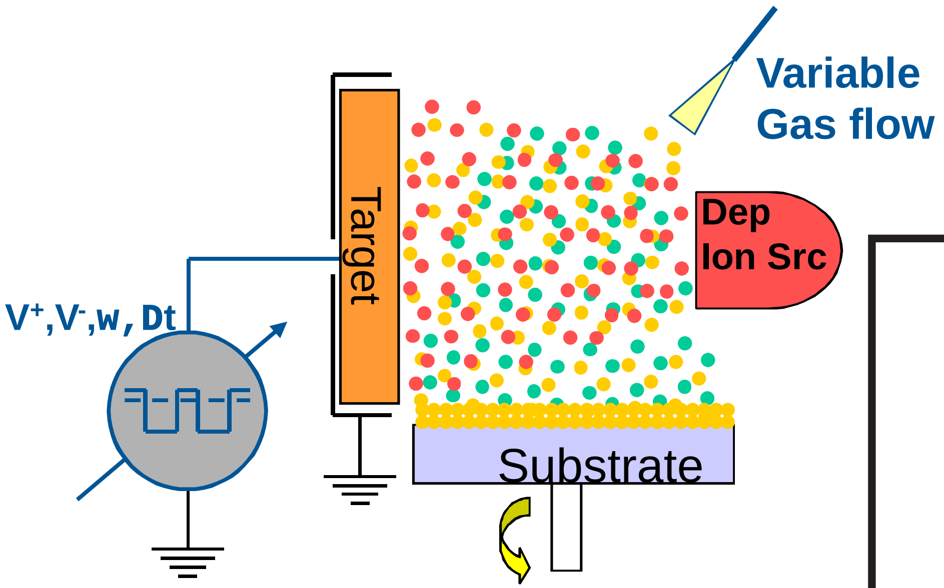


Low energy ions do not achieve high energies until they are near the target
Scattered ions will not sputter shields, they will hit the target.

Advantages of BTD

- Elimination of the problem of beam “overspill” in conventional IBD systems
  - This should reduce defects liberated from the shields
- Ion source does not need line of sight to source
  - Low energy ions are easily deflected to the target
  - Allows keeping ion source outside of high deposition areas that may lead to defects
- Control of thin film interfaces by varying the adatom and assist atom energies striking the surface of the growing film (from <1eV to >15eV)
  - Higher reflectivity is possible
- Better manufacturability than IBD may be possible
  - Potential for higher rates
  - Potential for wider process window
  - Potential for reduced consumables cost

BTD - Concept

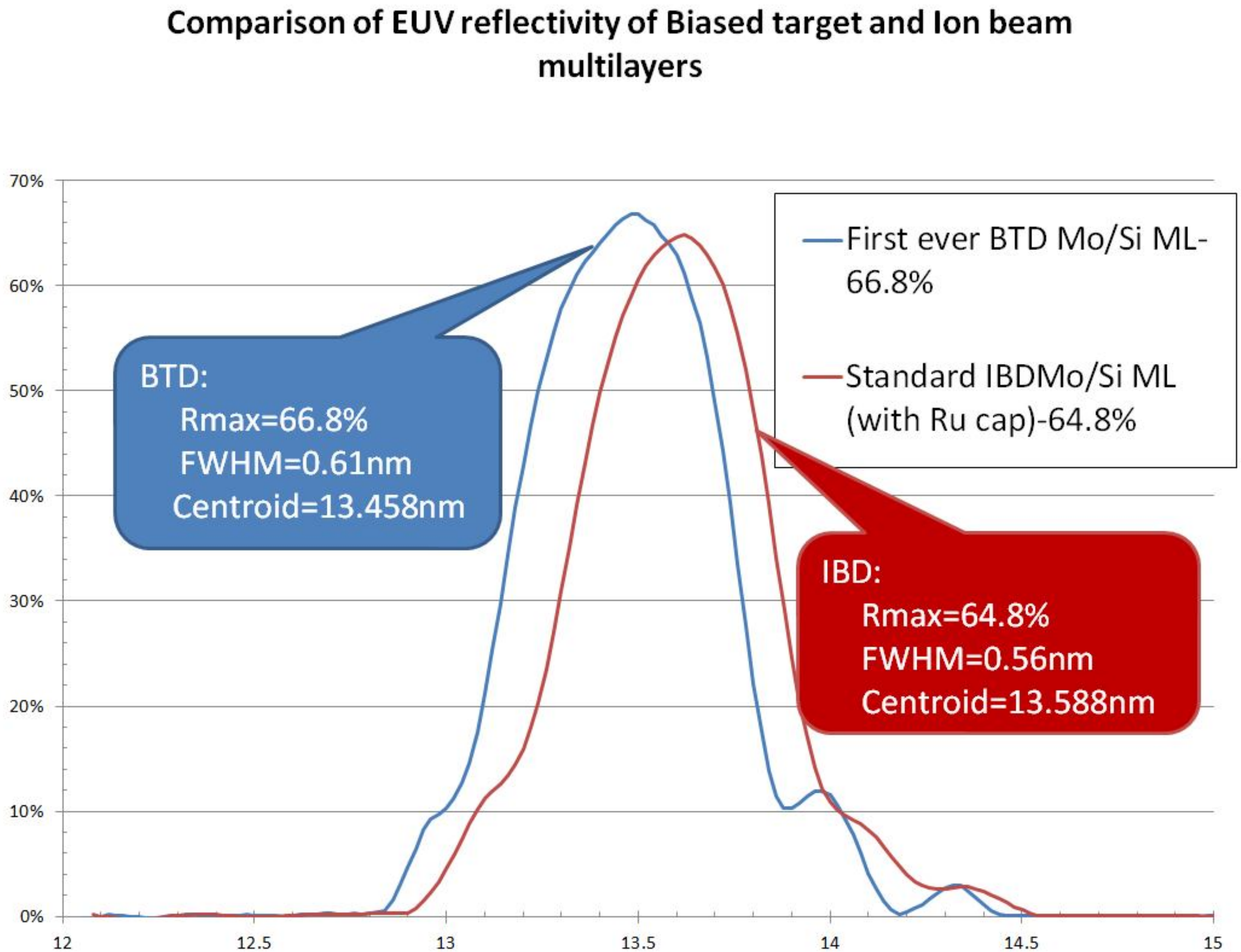


- Low voltage ion source
    - Reduced shield particles
- Pulsed power at target
    - Reduced target arcing

Evaluating BTD with 4Wave

- Initial evaluation criteria
  - Reflectivity
  - Uniformity
  - Run-to-run stability
  - Defect decoration
  - Defectivity

BTD reflectivity is ~2% greater than current IBD masks-Good



Uniformity-looks adequate

- The available BTD tools do not have the deposition geometry one would use to deposit masks.
  - The uniformity was adjusted to below 1% across the mask using the existing tool.
  - Based on this data and modeling, it is anticipated BTD can achieve EUV mask quality uniformity in several possible geometries.
- Although current BTD tools cannot demonstrate the needed uniformity, the <u>technique</u> should be able to achieve the uniformity goals.

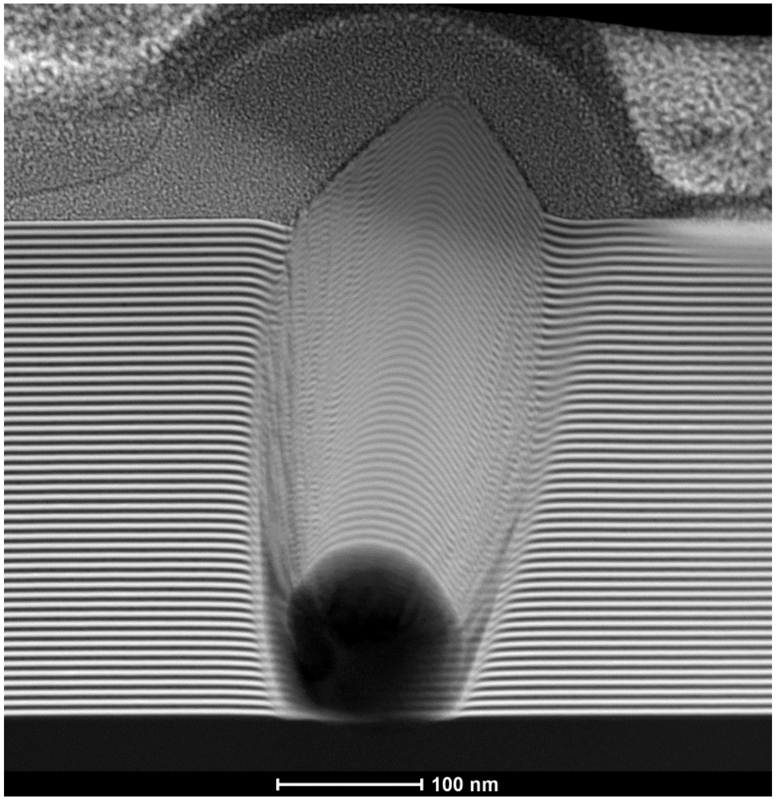
Run to run stability-needs improvement

- For mask blanks all point on every mask blank must fit in a 2.2% centroid band.
- BTD demonstrated a median run to run centroid change of 2% in the initial experimental run.
  - This needs to be significantly improved for production.
  - 4 Wave has a working theory about the cause and a fix is in progress.
  - Experiment will be repeated when fix is implemented.

Defect decoration-TBD

- Small defects on the substrate can grow larger with deposition and become killer defects.
- How large the defects grow is known to be dependent on the details of the deposition process.
- An initial sample with pre-marked defects is in production and will be evaluated with TEM to determine if the decoration is better or worse than IBD.

Example of an IBD defect growing



Defectivity – still a risk

- The tools available at 4Wave were not designed for low defectivity.
  - The coated substrate fixture retracts into the loadlock for pump/vent, leading to high defectivity.
- The collaborated with 4Wave to improve environmental defects has been limited by the tools design.
- Pumping/venting a substrate adds a few thousand defects.
- Process added defects look insignificant compared to the background defect level from pumping/venting.
- Defects remain the major risk item.

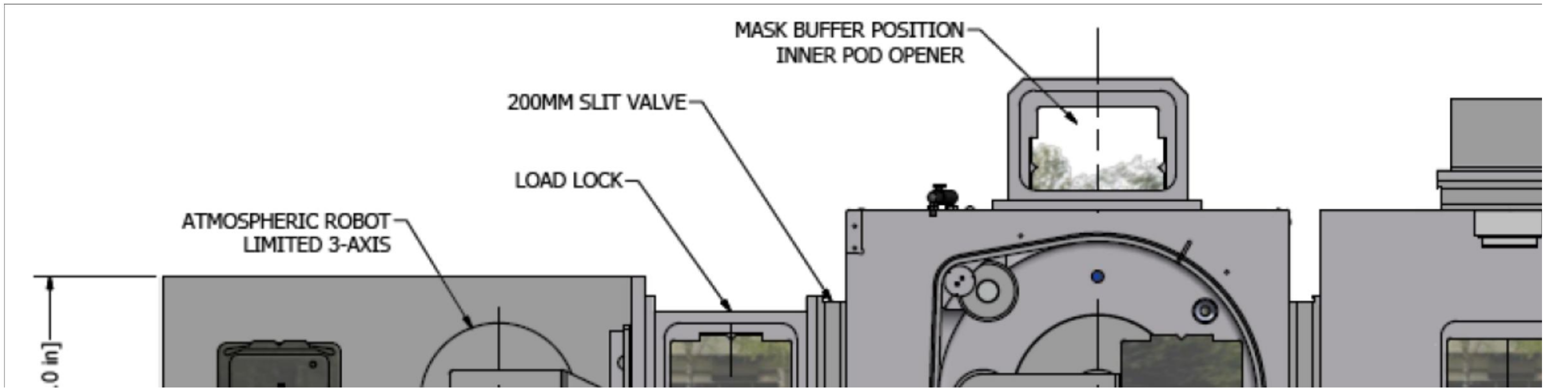
Risk scorecard

Risk	Status	Plan
Reflectivity	Better than IBD	
Uniformity	Geometry dependent, but behaves as predicted	Improve in new tool
Run-to-run stability	Needs improvement	Fixing, repeating experiment
Defect decoration	TBD	Design new tool to minimize
Defectivity	Few thousand (pump/vent)	Next slide

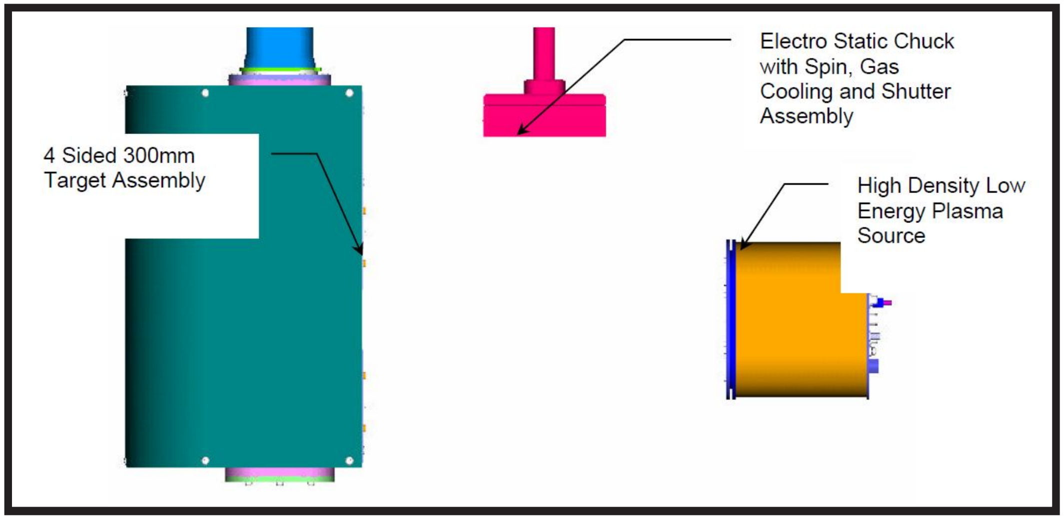
Risk reduction strategy

- Phase 1: Test 4Wave ion source defectivity in SEMATECH tool with known clean handling.
  - Will test ion source inherent defectivity.
  - Will not test actual deposition as tool does not have target bias capability.
- Phase 2: Build BTD mask blank risk reduction tool
  - Will allow closing remaining risk items.
  - Directly measure BTD process defectivity.
  - Improve/verify uniformity, decoration, and run-to-run stability.

4Wave proposed BTD mask risk reduction tool conceptual design



Internal views of one proposed tool



BTD IBD comparison

Factor	BTD	IBD
Defectivity	TBD	Approaching goals
Ion confinement	Should be better	Poor, leads to defects
Reflectivity	Better	Adequate
Uniformity	Close, controllable, will depend on final tool geometry.	Adequate
Repeatability	Needs work, but root cause identified.	Adequate
Target utilization	Good (90%+)	Poor
Productivity	Potential for major improvement	1-2hr/blank

Summary

- IBD remains the process of record for EUV mask coatings, but SEMATECH is testing alternatives for future EUV mask nodes.
- SEMATECH's working hypothesis is that IBD overspray causes many mask defects.
  - Work continues to validate this hypothesis.
  - Work to reduce the impact of this defect source continues.
  - BTD (Biased target deposition) is being evaluated as an alternative to IBD as it should not suffer from the same scattered ion problem.
- BTD evaluation
  - Reflectivity is better than IBD
  - Uniformity and run-to-run reproducibility need improvement
  - Defectivity is the major risk item.
  - Plan to evaluate BTD ion source defectivity.
  - BTD technology test mask production tool will then be used to manage the remaining risks.